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Effects of Water Quality on Hypoxia in the Gulf of Mexico

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Abstract

In many aquatic systems, incidences of low oxygen (hypoxia) waters have been causally linked to increased nutrient concentrations. The Mississippi River accounts for approximately 80-90% of the freshwater inflow to the Gulf of Mexico; water quality in the Mississippi River should serve as a indicator of conditions in the Gulf. Near its mouth, the Mississippi River splits, with approximately one-third of its discharge diverted into the Atchafalaya River. A review of the literature (primarily peer reviewed journals and technical publications) suggests that the Mississippi River waters enriches the Gulf of Mexico and this enrichment has increased in recent years. However, 21 years of data collected and published by the United States Geological Survey indicates no change in total phosphorus. Nitrogen values for the Mississippi River have increased (concomitantly with a decline in nitrogen values in the Atchafalaya River). There is good evidence that hypoxic areas in the Gulf of Mexico have increased following the 1993 flooding of the central-midwestern United States. The timing and intensity of river discharge into the Mississippi River apparently controls the duration and extent of hypoxia within the Gulf of Mexico.

Introduction

Concerns about declining water quality in the Gulf of Mexico have prompted detailed analyses of tributary water quality throughout the Mississippi River drainage basin. The purpose of this report is to summarize available information on the effects of upstream water quality on oxygen levels in the Gulf of Mexico as well as provide a general introduction to important concepts in aquatic ecology. Data presented herein was obtained from a variety of peer-reviewed scientific journal articles, technical reports by various national agencies, books, as well as personal communications with scientists in the field. The intent of this data summary is to provide examples of what factors may influence dissolved oxygen concentrations, and specifically, factors influencing the occurrence of hypoxia in the Gulf of Mexico.

It is important to realize that over 50% of Americans live within 50 miles of the coastline or along tributaries that drain into estuaries (Cromwell, 1971). High concentrations of people result in "hardening" or paving of land and alter natural patterns of water flow. These disturbances to natural water flow, along with point and non-point source pollution, influence downstream water quality, flow (volume), and health of the ecosystem. Historically, growth has been considered beneficial or an example of progress; appreciation of the impact that such decisions result in for future generations has redefined these concepts.

Knowledge of several terms or concepts is necessary to appreciate how increased nutrient loadings can adversely effect aquatic systems. Microscopic free floating algae in aquatic systems are autotrophic and called phytoplankton. Phytoplankton produce oxygen during the day as part of the conversion of light to chemical energy (via photosynthesis). Phytoplankton grow rapidly when nutrient concentrations (particularly nitrogen and phosphorus) are present and sufficient light and

CO_2 are available. Estuaries typically have a gradient of nutrient concentrations, with offshore waters lower in nutrients than nearshore areas. When rapid growth of phytoplankton occurs, a bloom can result. Blooms are defined as increases in cell abundance above normal or baseline concentrations. Eutrophication is defined as an increase in the rate of supply of organic matter to an ecosystem (Hinga *et al.* 1995). Blooms of phytoplankton can reduce dissolved oxygen concentrations by three mechanisms: (1) at night, plants respire consuming oxygen, (2) dense phytoplankton blooms reduce light, causing a reduction in the rate of photosynthesis and oxygen production, and (3) high concentrations of dead phytoplankton are metabolized aerobically by bacteria.

Phytoplankton serve as the initial food source for grazing animals (herbivores); herbivores typically are consumed by larger carnivores. Eutrophication results in more levels of trophic complexity-resulting in a less efficient transfer of food/energy to the highest carnivores. Succession patterns of phytoplankton in temperate systems include: in Spring when there is highest turbulence, large heavier phytoplankton cells dominate, whereas during summer-smaller, motile algae flourish. Highest nutrient concentrations in the water typically occur during Spring, as a result of runoff and/or mixing (turnover) in enclosed water bodies. Changes in phytoplankton composition can affect higher trophic levels (herbivores and carnivores) in several ways: not all phytoplankton species have the same nutritional value, and changes in the size or type of phytoplankton can result in food that is the wrong size for grazing animals. Changes in the type of prey items can reduce a grazer's health, increasing the susceptibility of that animal to disease or lowered reproductive efficiency or success.

Hypoxia is defined as the reduction of dissolved oxygen concentrations below two milligrams per liter; whereas anoxia is defined as water conditions in which no measurable dissolved oxygen is found. Reduced oxygen levels are stressful for resident faunal species, with reduced reproductive success or even mortality resulting from long exposure periods to reduced dissolved oxygen. During anoxic conditions, only organisms requiring minimal oxygen can survive. Anoxic regions are referred to as "dead water zones" due to reduced biota (both in diversity of species and concentration) in these areas.

General Characteristics of the Mississippi River Watershed and Gulf of Mexico

The Mississippi River is the largest source of freshwater discharge on the North American continent and ranks sixth globally in discharge volume (Berner and Berner 1987). Typically the Mississippi River is divided into two parts-the lower Mississippi consists of free flowing waters south of the confluence of the Ohio River (953.8 river miles). The upper Mississippi River has 29 navigation locks and dams that maintain navigable pools from Minnesota to Cairo, Illinois (846 river miles). Goolsby and Pereira (1996) reported riverine inputs to the Mississippi are dominated by the Ohio River (41% of total water); whereas the upper and lower Mississippi River contribute lesser amounts (22 and 23%, respectively). The Missouri and Illinois Rivers contribute even smaller discharge amount to the Mississippi River (10 and 4 %, respectively). Nutrient concentrations in these tributaries are not related to discharge; for example, the upper Mississippi River Basin contributes 51% of the total dissolved nitrate found in the Mississippi River (Figure 1). In a 1991-1992 United States Geological Survey (USGS) study, an estimated 15% of the commercial fertilizers applied to crops in the mid-West became non-point source runoff in Mississippi River waters (Goolsby *et al.* 1993). These studies used mass balance approaches, and did not directly measure the movement of nutrients from agricultural lands. Actual field measures of dissolved fertilizer loss are currently planned for the upcoming year (Goolsby, pers. comm.).

Suspended solids concentrations in the Mississippi River are high relative to other rivers (Table 1). High concentrations of suspended solids (particularly inorganic material) are typical of the Mississippi; concentrations of suspended solids increase 2000-fold from Minneapolis, Minnesota to Vicksburg, Mississippi. Increased concentrations of suspended solids reduce light penetration, thereby resulting in reduced phytoplankton growth in the river. The Mississippi River is nutrient rich and under conditions where light is not limiting to phytoplankton growth, able to support luxuriant phytoplankton biomass.

Tributaries to the Mississippi have a drainage area in 31 states of $6x10^6$ km^2, including agricultural, industrial, and urban centers. The Mississippi supplies approximately 90% of the total freshwater flow to the Gulf of Mexico (NOAA, 1987). Near its mouth, the Mississippi River divides, with approximately one-third of its net discharge directed into the Atchafalaya River. Approximately 53% of the river plume flows westward from the mouth of the Mississippi River, forming the Louisiana Coastal Current along the Louisiana-Texas coastline. This current is distinct from Gulf waters and is identifiable by its lower salinity. This area is typically the center of low oxygen water identified by researchers (Rabalais *et al.* 1996).

The Gulf of Mexico commercial fishery is the second largest in North America-both in the fish tonnage caught and in economic value (Table 2). Oyster harvesting in 1994 yielded 27 million pounds of shellfish having an economic value of $96 million (Gulfwatch 1996). Many of these fish species and invertebrates spend a portion of their lifetime in nearshore waters. Species which use seagrass/nearshore habitat as a refuge or foraging area include juvenile grouper, snapper, trout, shrimp, and scallops-all valuable commercial species. Lowered dissolved oxygen concentrations reduce fish swimming speed, cause weight loss by reduction of fish appetite, and reduce survival of fish eggs hatched under low oxygen conditions (EPA, 1971).

The central United States has been called the 'breadbasket' of the United States. This area produces approximately 80% the country's grain supplies, particularly wheat, corn, and soybeans (Table 3). Iowa and Indiana, in fact, accounted for nearly 20% of the total country's production of corn in the 1980's (The World Almanac 1995).

Growth of Region

The Mississippi River serves as a potable water source, has significant sports and commercial fisheries, provides water for chemical and agricultural industries, and has an important role as the nation's central "aquatic highway" for transportation. Over 70 cities use the Mississippi River as their primary drinking water supply (Meade 1996). Almost 60% of the inland waterway freight traverses the Mississippi River and New Orleans, LA handles the largest volume of foreign freight of any American city (The World Almanac 1995). Median concentrations of fecal coliform bacteria (indicative of untreated sewage) exceeded recreational full contact levels at 12 of 30 sampling sites sampled during 1982-1992. Concentrations tenfold higher than acceptable levels are typical downstream of St. Louis, Missouri, Rock Island, (Quad Cities) Illinois, and Memphis, Tennessee. Population density increases along the Mississippi River have been rapid in selected areas of the region, whereas other state's populations have been steady for five decades (Table 4).

Hypoxia in the Gulf of Mexico

Hypoxic waters typically occur during May-September on the Louisiana coastal shelf. Bottom waters (waters below the pcynocline at 10 m) have lower oxygen levels during periods when surface to bottom salinity differences are greatest. During the summer of 1993, record amounts of Mississippi River discharge were recorded (at 75-300 yr frequencies). Nutrient levels were either equal to (Goolsby *et al.* 1994) or potentially greater than typically recorded during this period (Whitledge 1994 in Dowgiallo 1994). The total amount of nutrients delivered to the Gulf was higher than previous years due to the increased amount of water. The aerial extent of the hypoxic zone during 1993 doubled relative to previous years (Rabalais *et al.*, in press). Rabalais *et al.* (1996) presents data showing changes in phytoplankton composition relative to two previous studies conducted in the 1950-1960's; the use of three studies by unrelated researcher groups could account for reported differences in speciation. Moreover, published phytoplankton species lists for Graveline Bayou, Mississippi (Zimba 1990) identified all species found on the lists in Rabalias' (1996) article. The density of cyanobacteria reported in Rabalais' study is well within that reported in Zimba (1990); the use of cell numbers to discuss phytoplankton composition is not as useful as use of cell biovolume, pigment markers, or other standardization techniques

There is evidence that nutrient limitation occurs in the river plume; silicon has been identified as limiting phytoplankton growth by several researchers (Lohrenz *et al.*, unpublished, Nelson & Dortch 1996). Changes in silicon loading to the Gulf of Mexico has been suggested in recent analyses (Justic *et al.* 1995); these studies have used hindcasting techniques to estimate historical nutrient concentrations and compared these results to limited nutrient data sets from the late 1950's. These techniques are linear modeling efforts using very limited data sets and interpretations derived from these should be used cautiously. Silicon limitation following nitrogen and phosphorus enrichment has been observed in several marine systems (Hinga *et al.* 1995).

Management of Hypoxia in the Gulf of Mexico

Since 1988, a number of governmental agencies have been involved with developing a management plan that maintains the health and productivity of the Gulf of Mexico. Directed by the Environmental Protection Agency, the Gulf of Mexico Program has expanded its work to include public education/outreach, coordination of research programs, and initiation of demonstration projects. The Gulf of Mexico Program is not a regulatory program; its goal is to use voluntary Best management practices recommended for agricultural areas include use of artificial wetlands and buffer strips to minimize runoff and erosion, as well as manure storage in structures to prevent runoff. Work in artificial wetlands in North Dakota indicate that most runoff of pollutants occurs during the first one or two significant storm events after spring planting (Downer & Meyers 1996). Collectively these approaches should reduce nutrient and pollutant loading to the Gulf of Mexico. Similar approaches used in the Chesapeake Bay watershed have resulted in significant reductions in nutrient loading by the two largest tributaries to the southern Chesapeake Bay (Bell *et al.* 1996).

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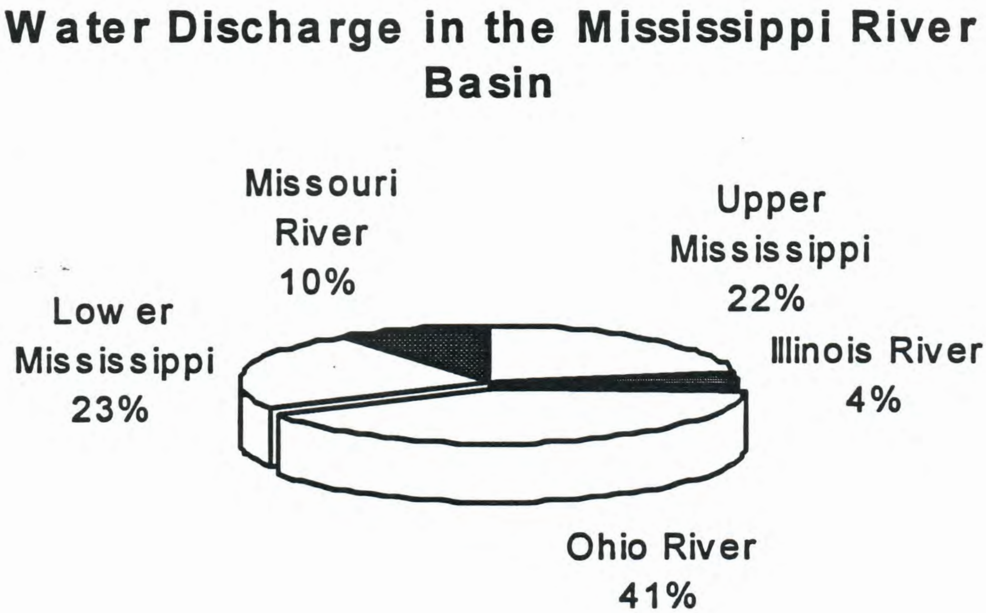
Figure 1. Water Discharge and nitrate sources in the Mississippi River



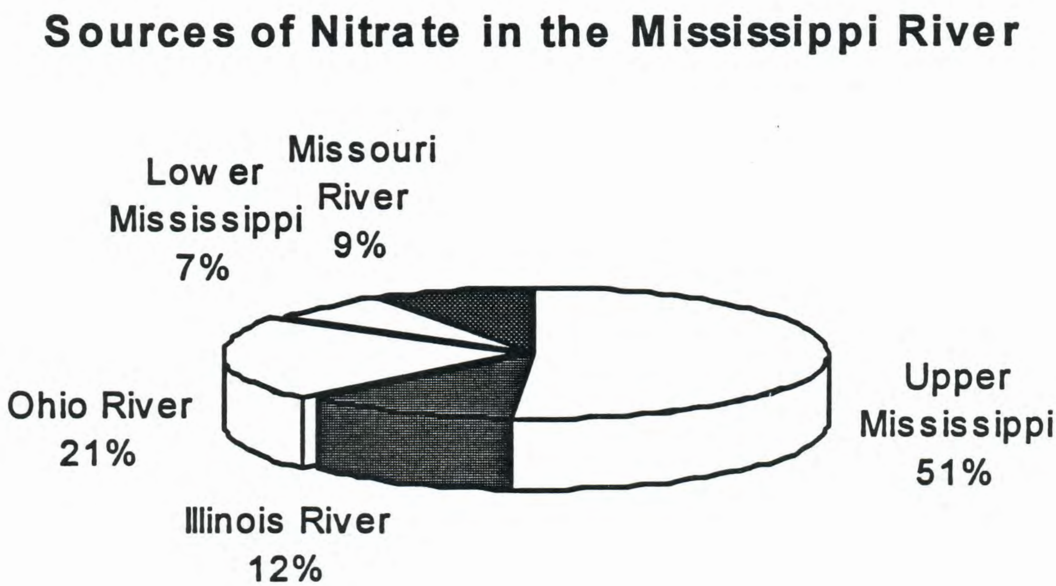


Table 1. Discharge rates of major rivers in the world

River	Locale	Dissolved Solids ($x\ 10^6$ Tons/Yr)	Drainage Area ($x\ 10^6\ km^2$)
1. Amazon	South America	223.0	6.15
2. Zaire (Congo)	Africa	36.0	3.82
3. Orinoco	South America	39.0	0.99
4. Yangtze	Asia (China)	226.0	1.94
5. Ganges-Brahmaputra	Asia	136.0	1.48
6. Mississippi	North America	125.0	3.27
7. Yenesei	Asia	65.0	2.58

Table 2. Importance of the Gulf Fisheries to the United States (x 1,000)

Area	Catch	$ Value
North Atlantic Seaboard	604,697	552,280
Middle Atlantic	257,537	154,989
Chesapeake Bay	813,283	161,516
South Atlantic	250,346	161,314
Alaska and North Pacific	6,759, 704	1,722,396
Gulf of Mexico	1,714,772	630,738
TOTAL	10,466,895	3,471,460

Table 3. Annual Grain Crop Production in the United States

Year	Corn[1]	Wheat[1]	Oats[1]
1970	4,152,243	1,351,558	915,236
1975	5,828,961	2,126,927	638,960
1980	6,639,396	2,380,934	458,972
1985	8,876,706	2,425,105	520,800
1990	7,934,028	2,736,428	357,524
1994	10,103,030	2,320,610	229,857

[1] x 1,000 bushels

Table 4. Population Densities of Selected States (As People/Square Mile)

State	1960	1970	1980	1990
Idaho	8.1	8.6	11.5	12.2
Illinois	180.4	199.4	205.3	205.6
Iowa	49.2	50.5	52.1	49.7
Louisiana	72.2	81.0	94.5	96.9
Ohio	236.6	260.0	263.3	264.9
Wisconsin	72.6	81.1	86.5	90.1
U. S.	50.6	57.4	64.0	70.3